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Technical Report No. 177

Evaluation of the Nimrod Gauge Adjustment Scheme. A report to the Nimrod Project Board

by

M Hackett and M Kitchen

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1. Introduction.

In recent years, improved quantitative monitoring of radar data has revealed that some radars in the UK network suffer from errors in their sensitivity. The causes of the errors are not easily explained and the present hardware calibration procedures appear to be unable to rectify the situation. Significant changes in sensitivity are observed on timescales of a few months down to a few minutes. These effects are larger than could be explained by systematic changes in the Z-R relationship or other errors of meteorological origin. Radar correction procedures within the Nimrod system are designed to correct for the effects of the bright band, range and orographic growth. For a well calibrated radar, these corrections have been shown to be capable of significantly reducing the errors in surface precipitation rate estimates (e.g. see Kitchen et al, 1993). However, the quality of the rainfall analyses is affected in some cases by sensitivity errors which can be as large as a factor of two or more.

It was hoped that the improved radar monitoring combined with new radar calibration procedures could be introduced before the implementation of Nimrod and reduce the need for gauge adjustment. Unfortunately, progress remains elusive and there is a need to introduce some method of correction for sensitivity errors within the Nimrod radar processing. Accordingly, a gauge adjustment procedure has been designed and tested. The principles behind the design are given in Kitchen (1995), although not all the features have been included in initial implementation. A brief description of the scheme is given in Section 2. The design is aimed at correcting for persistent or slowly varying sensitivity errors.

The scheme has been run in a simulation of operational conditions since November 1994 although some changes have been introduced since this date. The simulation was not perfect in that the adjustments were applied to the radar data after they had been corrected for the errors due to the vertical profile of reflectivity. In an operational implementation, adjustment is more accurately made before these corrections because they are non-linear in rainfall rate. The difference should be small but the results of the evaluation may give a marginally pessimistic view of the performance of the scheme. A more significant problem is that at present, the Nimrod system processes data at 15 minute intervals. Hourly totals computed from the radar data will be subject to significant uncertainty arising from temporal sampling errors (see e.g. Wilson and Brandes, 1979, Bellon et al, 1991 and Kitchen and Blackall, 1992). This uncertainty will degrade both the accuracy of adjustment and the results of the evaluation. Nevertheless, it was considered necessary to consider implementation of a gauge adjustment scheme at this stage to try and alleviate some of the radar calibration problems.

The evaluation has concentrated on the performance of the Chenies radar during two periods, one of mainly widespread frontal rainfall during January 1995 and another of mainly convective rainfall during July 1995. The results are presented in section 3. Finally, some recommendations are listed in section 4.

2. The Adjustment Method.

The adjustment method is based upon comparisons of hourly accumulations from gauges (G) with hourly integrations of radar estimates for the collocated pixel (R). An adjustment factor is computed on the assumptions that:-

a) The origin of the bias error is linear in rainfall rate (as distinct from e.g. an error which is linear in reflectivity factor). This is the simplest assumption given that the true relationship is unknown.

b) That the gauge accumulations can be used as estimators of the true accumulation averaged over the collocated radar pixel, and no significant bias errors are introduced by sub-pixel orographic effects.

The most sensitive user of quantitative radar data are the National Rivers Authority (NRA) Regions, who use the data in operational flood forecasting. For these purposes, high rainfall rates are more critical and it is important to eliminate bias errors in rainfall accumulations over catchments as far as possible. For this reason, the radar adjustment factor is computed as the ratio of the total gauge accumulation over the integrated radar total summed over all the gauge comparisons (see also Wilson and Brandes, 1979).

i.e. $m=\sum R/\sum G$

The method is one of successive adjustment, i.e. the values of R are subject to the adjustment currently in force and thus the total adjustment applied to the radar data is the product of all the individual adjustment factors applied up to that time.

A more common method of adjustment seeks to minimise the RMS error in log (R/G). However, this approach was considered to place too much emphasis on low rainfall rates which were less important to the users. Radar/gauge comparisons are subject to very large representativeness errors which can easily conceal quite large underlying bias errors. The challenge of any gauge adjustment scheme is therefore to extract the true bias and avoid the imposition of spurious, unrepresentative adjustment. An important feature of any gauge adjustment scheme is quality control. The following quality control steps are performed on the individual comparisons.

a) Comparisons are ignored unless the radar detected precipitation in the gauge pixel in at least 4 out of the 5 samples during the hour (the Nimrod radar sampling interval is currently 15 minutes). This is intended to reduce the impact of data from small-scale convective

conditions, when representative errors could be expected to be greatest. It also reduces the impact of detection failures, which must be distinguished from sensitivity errors.

b) Comparisons are only accepted if both gauge and radar both record > 0.2mm during the hour. This avoids most comparisons when the radar is affected by residual clutter or anaprop.

c) The radar estimates of surface precipitation rate are subject to large uncertainties at long range, particularly when the freezing level is low. Only gauge within 100km of the radar are normally considered and provides an acceptable number of comparisons except in the case of the Jersey and Shannon radars, for which the acceptable range is relaxed to 150km.

d) A few gauges which persistently give unrepresentative comparisons have been excluded. These gauges may be in pixels which are frequently cluttered or subject to very large corrections due to severe occultation.

The need to ensure that adjustments are representative means that the scheme cannot hope to respond to very rapid fluctuations in radar sensitivity. Adjustment of each radar is considered at 7 day intervals. If more than 50 valid comparisons have been obtained since the previous adjustment was applied, then a new adjustment factor m and an estimate of its error are computed. The error estimate is used in the following tests of significance.

a) If the uncertainty in adjustment is above a threshold (fixed as a result of experience), then no adjustment is applied but comparison data collection continues.

b) If the uncertainty is acceptable but the adjustment is close to 1, then a factor of 1 is applied. This is to avoid making continual minor adjustments to a stable radar.

c) If the uncertainty is acceptable and the adjustment is significantly different from 1, then the adjustment factor is applied to subsequent radar data.

3. Evaluation Results.

Fig 1 shows the simulated time history of all the accepted adjustment factors applied to the radar data from each site from November 1994 up to June 1995. The scales on the y-axis are not the same for all the radars. These graphs highlight some of the problems the adjustment scheme is attempting to alleviate.

a) Adjustment factors for many of the radars in the network (numbers 3,4,5,6,8,9,11,14,15,16) are mostly above 1, suggesting that these radars are usually insensitive. Some radars require large adjustments to be applied continuously (e.g. radar 8).

b) The assumption that the adjustments are dominated by radar sensitivity errors is supported by the observation that some radars show much more stability of adjustment than others. e.g. the adjustments applied to the radar 17 (Dublin) all lay between 0.5 and 0.85 and for

radar 7 (Castor Bay) between 0.7 and 1.3. In contrast, radars 9 and 10 (Ingham and Dyfed) are relatively unstable, showing much larger variability. In the case of Dyfed in particular, the variations were almost certainly not being resolved by the adjustment process.

c) Radar 13 (Corse Hill) suffered from a specific fault during the first two weeks in December 1994. The radar sensitivity collapsed over the course of a few days and an adjustment factor of greater than 4 was in force during one week.

The impact of the Nimrod corrections and simulated adjustment was quantified by comparing integrated hourly radar totals with hourly gauge accumulations. Two periods were selected as being representative of very different synoptic conditions. The precipitation during January 1995 was mainly widespread frontal rainfall with a low freezing level. In contrast, the precipitation during July 1995 was dominated by showers with some larger convective storms. To ensure consistency between the two sets of comparison statistics, the data from the January period was re-processed using the version of the adjustment scheme current in July 1995.

Three types of radar data were compared with the gauge data. 'Uncorrected' is the data as received from the radar site but with any radar site gauge adjustment removed. For the July dataset, the uncorrected data has also passed through the Nimrod anaprop deletion process. 'Corrected' data result from the Nimrod correction process for the effects of bright-band, range and orographic growth. 'Adjusted' are after the proposed Nimrod gauge adjustment scheme has been applied. In Table 1 are the mean (radar-gauge) and RMS differences (in mmh^{-1}) computed over all the hourly comparisons in 50km range bands. RMSf is the antilog of the RMS log (R/G) and represents the fractional difference. In addition, a mean difference was computed for each radar over all ranges.

Table 1a shows statistics based upon comparisons between radar 5 (Chenies) and Met. Office hourly gauges for January 1995. The uncorrected radar data shows that the radar overestimated precipitation rates at short range (presumably due to bright band) and suffered from increasing underestimation at long range. The Nimrod corrections helped to eliminate most of the range dependence at short and moderate ranges but revealed an overall bias which is ascribed to a radar sensitivity error. The gauge adjustment applied adjustment factors of around 1.5 during this period and this resulted in a much reduced overall bias compared to the corrected data. Most of the RMSf differences for all three sets of data were around 2 and representativeness errors probably made a significant contribution to the random differences. Nevertheless, the RMSf values for the adjusted data were lower than those for the uncorrected data in all range bands, with a large reduction achieved at long range.

Table 1b is also for the January period but using gauge data from the NRA Thames network. Note that the NRA gauge data currently plays no part in the radar adjustment process as the data are not received in real-time. Almost all the NRA gauges are within 100km range of the Chenies radar and the results from these gauges show similar characteristics to those in Table 1a.

Table 1c is similar to Table 1a but for the month of July 1995. A small number of comparisons obtained from thunderstorms on the 26th July produced anomalous results (radar measurements up to an order of magnitude higher than gauge totals, even at short range). The reason is unknown, but a temporary radar fault, anaprop or the presence of hail are all possibilities. This day was therefore excluded from the statistics. With the high freezing level and lack of orographic enhancement, the corrections for the vertical profile of reflectivity were very small out to 100km range. At longer ranges, the Nimrod corrections proved very beneficial in reducing serious radar overestimation of surface precipitation rates in some convective storms. Similar to January, the corrections tended to smooth out the rage dependence but an overall bias remained. This was much reduced by adjustment, but at the expense of an increase in RMS errors compared to the corrected data.

As noted above, hourly comparisons using 15 minute/5km resolution radar data are subject to significant representativeness errors. It is possible to estimate their contribution to the observed differences using information from Kitchen and Blackall (1992). Using data from a high density gauge network, they estimated the representativeness error (RMS log R/G) associated with 15 minute sampling and a 5km radar pixel to be about 0.28 but only 0.15 for a 5 minute sampling interval. The gauge data used in their analysis was obtained mainly in convective conditions and therefore will overestimate the representativeness errors for the January evaluation period. For the July comparisons, their contribution to RMS log R/G was assumed to be equal to 0.28. Thus 0.28^2 was subtracted from the mean square value of log R/G and the RMSf recomputed. The results in the last column of Table 1c then represents our best estimate of the fractional error in the radar estimates of the hourly surface precipitation rate. These must be regarded as rough estimates, as the estimated representativeness error is of the same order as radar-gauge differences. A more reliable determination of the quantitative accuracy of the Nimrod hourly surface precipitation estimates requires higher resolution radar data. Jacquet and Cheze (1989) also noted that 15 minute radar sampling was inadequate for forming hourly totals and the temporal sampling errors were responsible for most of their observed scatter in radar/gauge comparisons.

The impact of representativeness errors on the January gauge comparisons can also be gauged by computing statistics of the radar-gauge difference averaged over many comparisons. The averaging reduces the contribution of from the mainly random representativeness errors through cancellation. The mean hourly precipitation rate recorded by each gauge within 100km of the radar was computed, along with the mean rate in the collocated radar pixels. Only those hours with a valid comparison were included in the averages to exclude the effects of residual anaprop etc. Statistics were then computed, as before, but with each gauge site providing only a single comparison. These statistics are reproduced in Table 2. They suggest that the correction and adjustment processes are making a much larger impact on the accuracy of the surface precipitation estimates than suggested by Table 1a and 1b; with the RMS error being reduced by about a third in both cases. A reduction was achieved in both the bias errors and the gauge-to-gauge scatter.

Although the performance of the Chenies radar appears typical of many radars in the UK

network (see Fig 1), the evaluation was extended to include other radars. Results are presented from two which show markedly different characteristics; radar 17 (Dublin, operated by the Irish Meteorological Office) which appears to have a relatively stable calibration but is slightly oversensitive and radar 8 (Predannack) which appears to be very insensitive. Table 3 presents the results of gauge comparisons for the period from 17th Mar 1995 (the date of the most recent change to the adjustment scheme) to the 1st Aug for these two radars along with Chenies for completeness.

For both Dublin and Predannack, the bias errors in the uncorrected and corrected data appear to be dominated by the calibration error. Gauge adjustment of Predannack appears to have overcorrected for the insensitivity on average, but the bias error was considerably reduced compared to the uncorrected data. The corrections applied to the Dublin radar were remarkably successful in reducing the range dependence in the bias and also achieved a worthwhile reduction in the RMS errors at most ranges. After adjustment, the bias at all ranges was less than $0.2mmh^{-1}$.

4. Conclusions.

A gauge adjustment scheme has been developed for Nimrod which is designed to eliminate mean biases due to serious imperfections in radar calibration. In realistic simulations, the scheme proved mostly effective in this role, particularly for radars exhibiting large persistent sensitivity errors. On this basis, it is recommended that the gauge adjustment scheme is implemented as it stands within Nimrod for those radars which have a history of persistent sensitivity errors.

These tests of the adjustment scheme were to some extent compromised by the representativeness errors associated with the radar-gauge comparisons. It was found that representativeness errors made a significant contribution to the observed scatter between hourly gauge accumulations and radar totals based upon 15 minute/5km resolution data. The additional scatter will also have reduced the accuracy of the computed adjustment factors and the ability of the scheme to avoid unrepresentative adjustments. It is therefore recommended that radar data processing interval in Nimrod is reduced to 5 minutes as soon as practicable. Tests using data from a single radar at the reduced sampling interval could be used to quantify the benefits from such a change.

A fundamental problem common to all gauge adjustment schemes is the response cannot be instantaneous. Any high frequency variations in sensitivity are improperly resolved and adjustment cannot adequately compensate for them. It is recommended that every effort is made to improve the stability of the radar hardware. If no improvement can be achieved, then an increase in the frequency of adjustment should be considered. For some radars in the network, this could be facilitated if NRA hourly gauge data could be acquired in real-time. If the stability of the calibration improves, then gauge adjustment should be retained to alleviate errors due widespread variations in the Z-R relationship or any gross errors in the

meteorological corrections.

Assumptions about the nature of the sensitivity errors have to be made (e.g. linearity in rainfall rate) which may be erroneous. The errors associated with the assumption will depend upon the size of the adjustment. Thus, it is important to establish the reason for the apparent insensitivity of some radars in the network with the intention of reducing the magnitude of the adjustments that are required.

The ability of the gauge adjustment scheme to detect the fault on the Corse Hill radar (see Fig 1) suggests a role for the gauge comparison dataset in diagnosing radar faults. For example, the gauge adjustment scheme could generate warnings if the total adjustment applied to the radar data went outside prescribed limits (outside the range 0.5 to 2, say). For the detection of sudden large changes in sensitivity, a separate monitoring program could be developed. This could examine the results of the gauge comparisons more frequently than the adjustment scheme and perhaps use more relaxed quality control. Such a program could alert users and the maintenance organization, but not attempt to make adjustments to the data.

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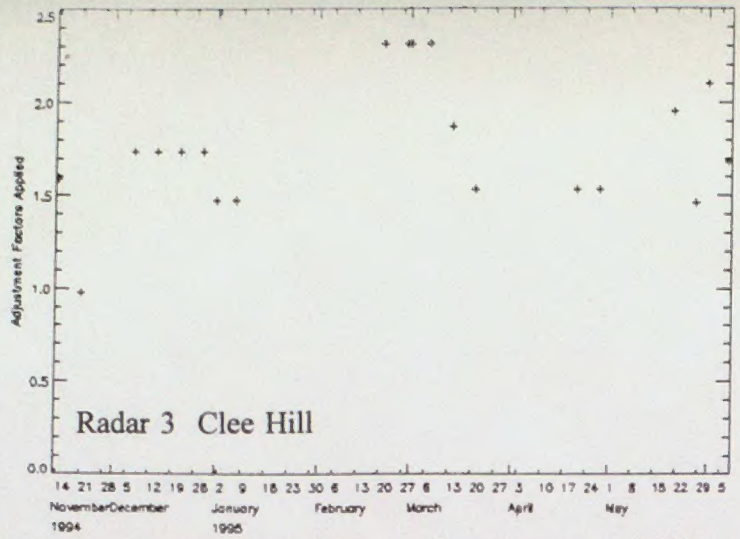
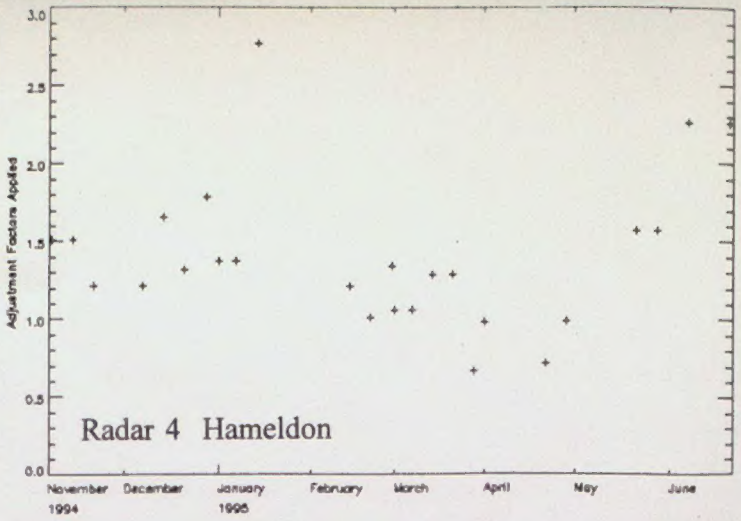

Adjustment Factors Applied
Radar 3 Clee Hill
November December January February March April May
1994 1995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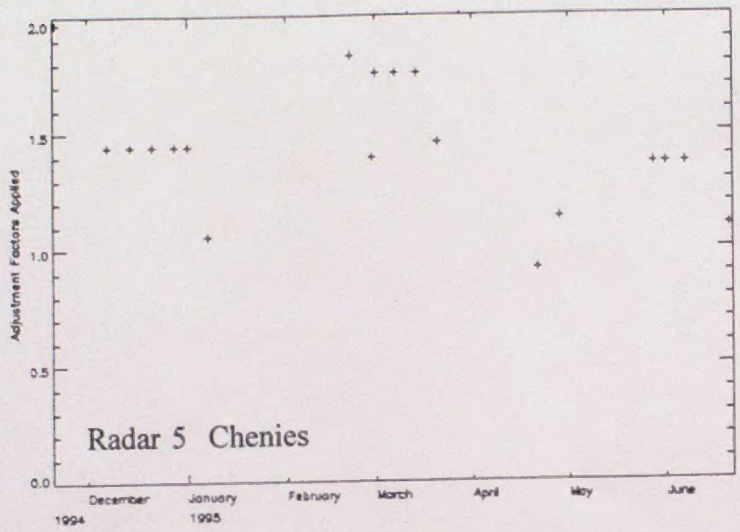
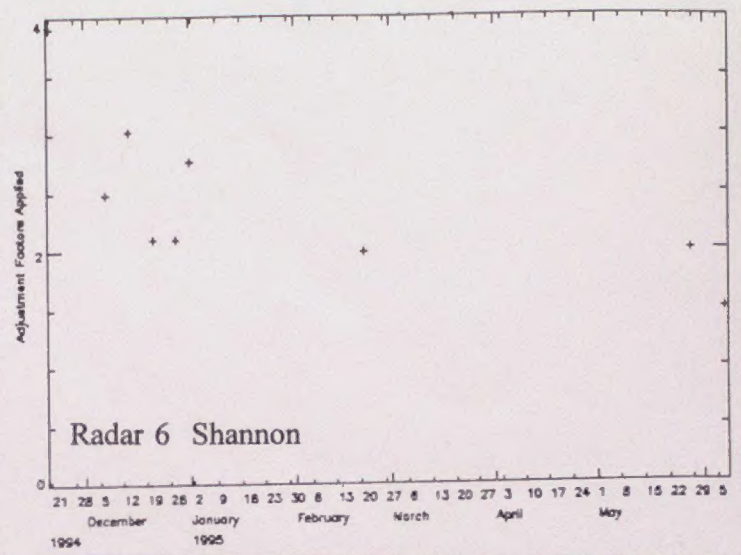
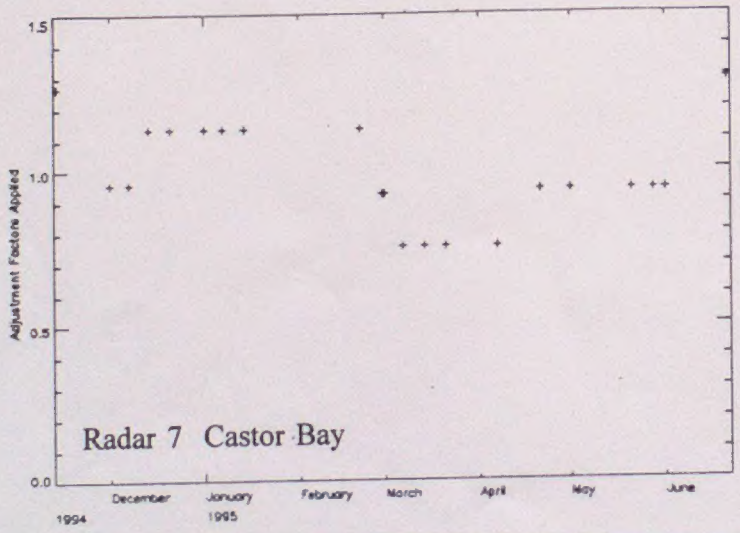
November December January February March April May June
1994 1995


Adjustment Factors Applied
Radar 5 Chenies
December January February March April May June
1994 1995


Adjustment Factors Applied
Radar 6 Shannon
December January February March April May
1994 1995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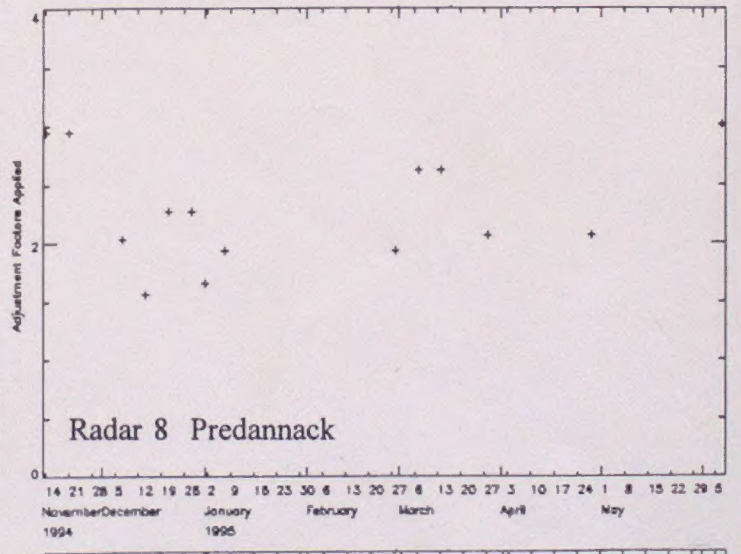
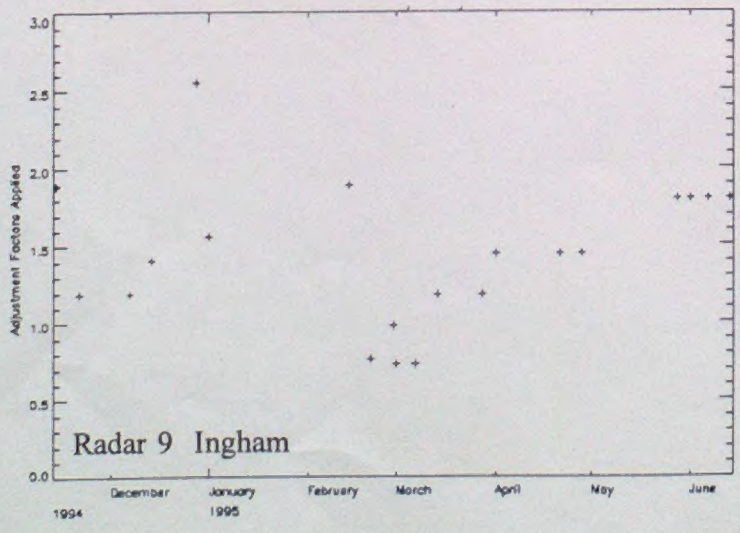
Radar 7 Castor Bay
December January February March April May June
1994 1995


Adjustment Factors Applied
Radar 8 Predannack
November December January February March April May
1994 1995


Adjustment Factors Applied
Radar 9 Ingham
December January February March April May June
1994 1995

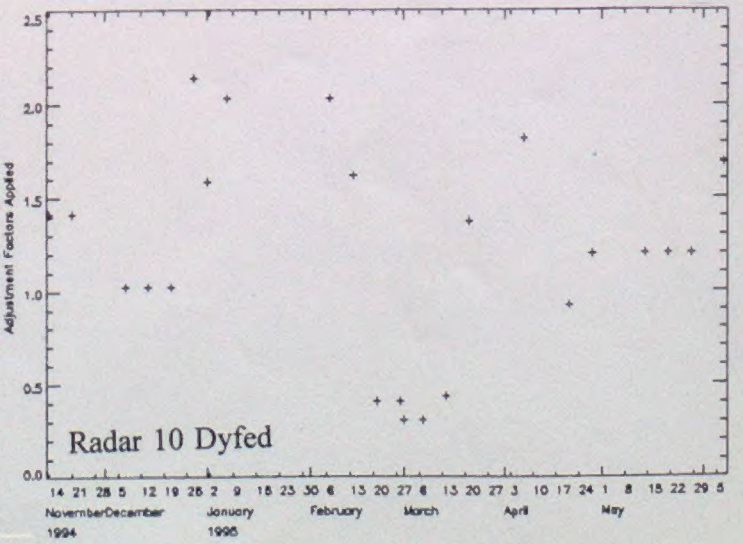
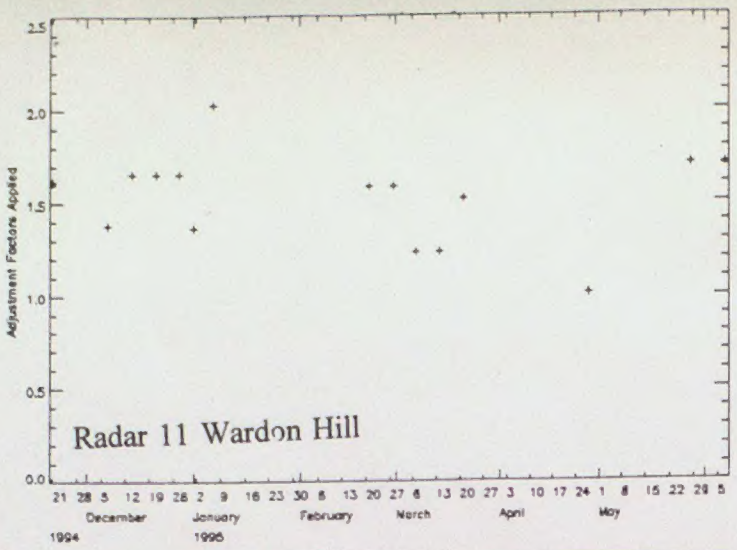
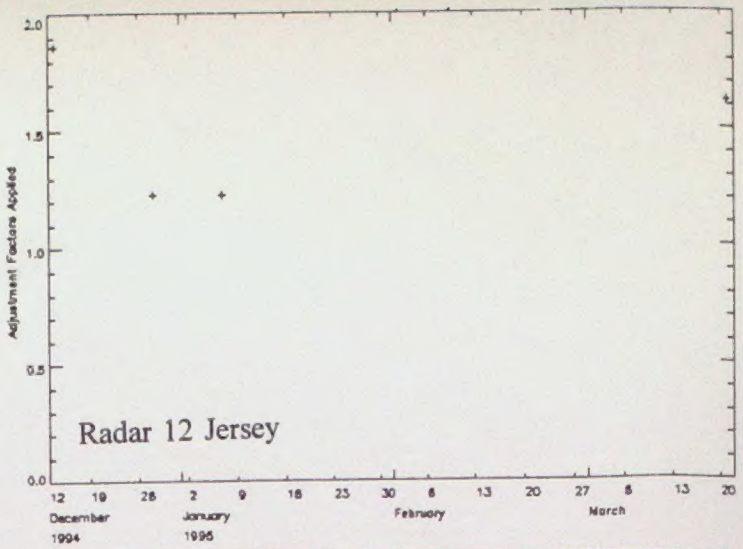
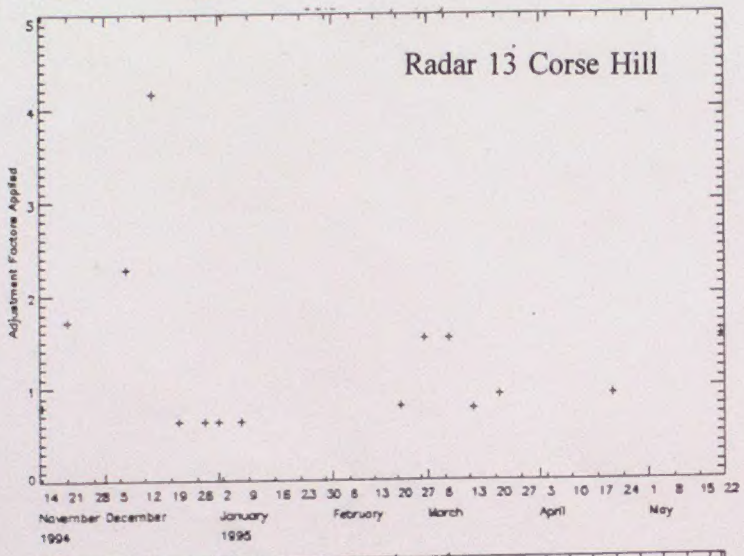
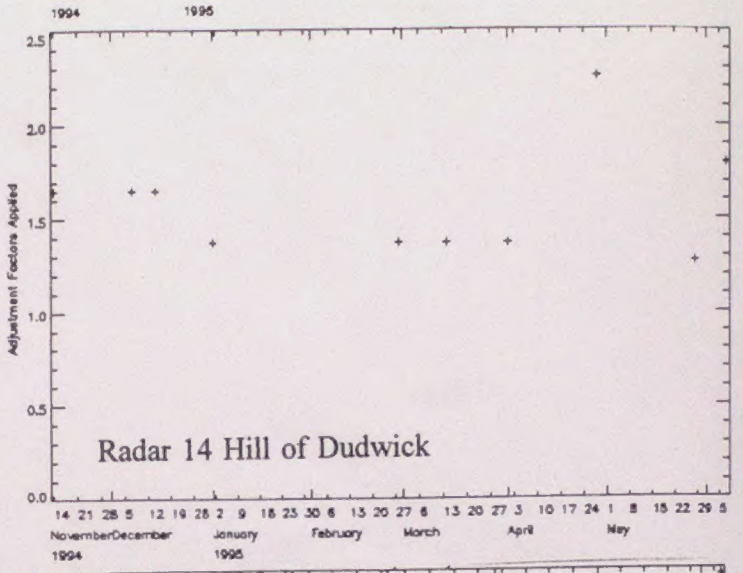

Adjustment Factors Applied
Radar 10 Dyfed
November December January February March April May
1994 1995

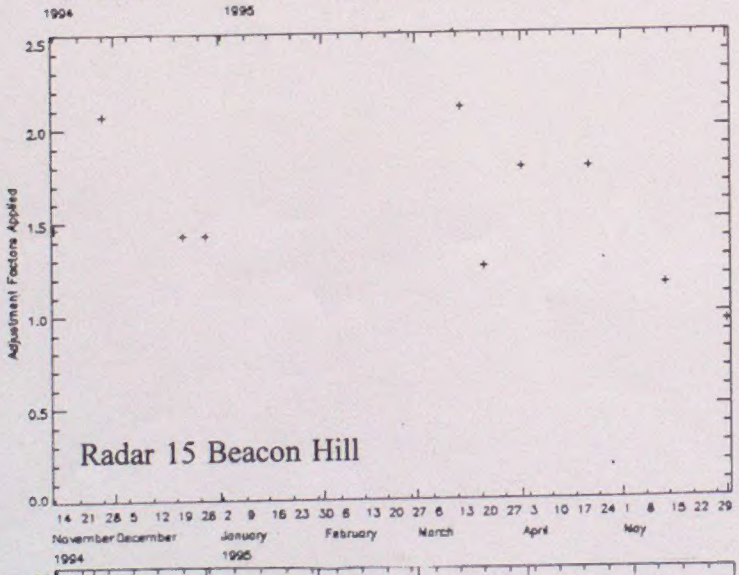
Fig 1

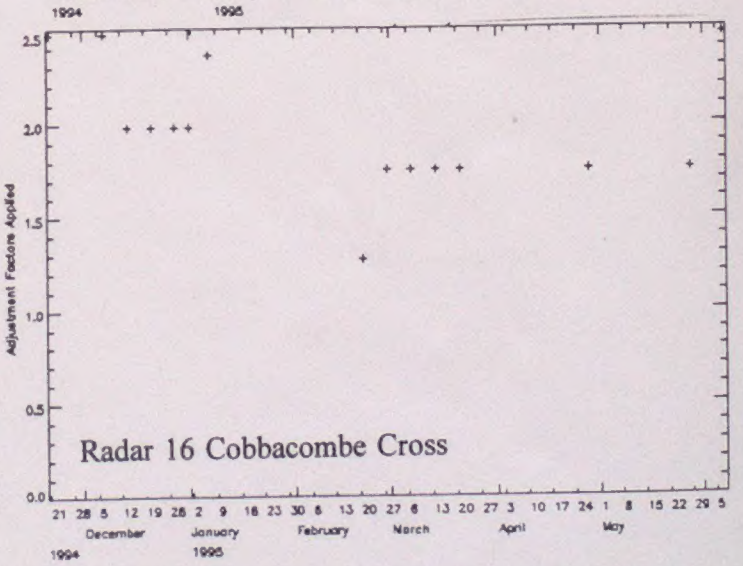

Radar 11 Wardon Hill
Adjustment Factors Applied
December
January
February
March
April
May
1994
1995


Radar 12 Jersey
Adjustment Factors Applied
December
January
February
March
1994
1995


Radar 13 Corse Hill
Adjustment Factors Applied
November
December
January
February
March
April
May
1994
1995


Radar 14 Hill of Dudwick
Adjustment Factors Applied
November
December
January
February
March
April
May
1994
1995


Radar 15 Beacon Hill
Adjustment Factors Applied
November
December
January
February
March
April
May
1994
1995


Radar 16 Cobbacombe Cross
Adjustment Factors Applied
December
January
February
March
April
May
1994
1995

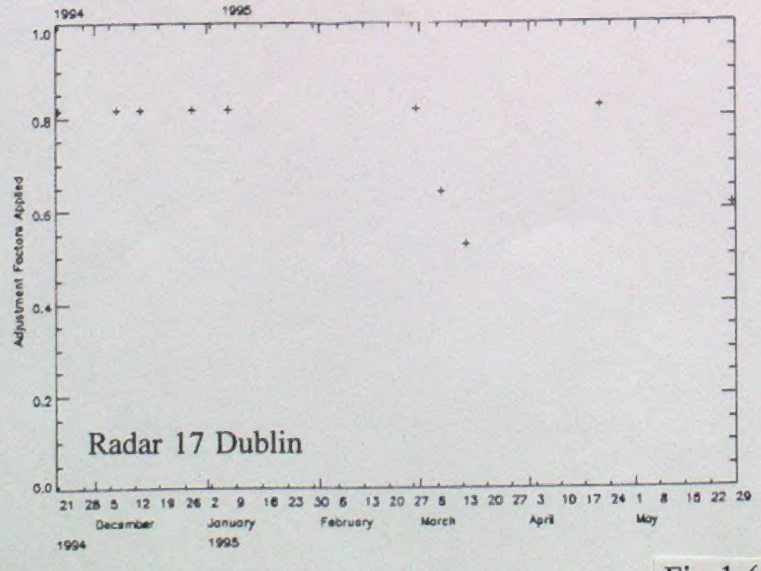

Radar 17 Dublin
Adjustment Factors Applied
December
January
February
March
April
May
1994
1995

Fig 1 (cont.)

Table 1a

Comparison between radar 5 (Chenies) and Met. Office gauges - Jan 1995

		Uncorrected			Corrected			Adjusted		
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf
0- 50	274	-.09	.95	1.93	.26	.78	1.92	.03	.84	1.87
50-100	442	.31	1.05	2.25	.38	1.07	2.14	.10	1.29	2.06
100-150	533	.76	1.32	2.75	.70	1.31	2.60	.49	1.23	2.37
150-200	46	1.64	2.20	4.20	1.20	1.86	2.94	1.02	1.76	2.67
overall		.46			.51			.28		

Table 1b

Comparison between radar 5 (Chenies) and NRA Thames gauges - Jan 1995

		Uncorrected			Corrected			Adjusted		
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf
0- 50	2407	-.03	1.20	2.10	.33	.99	2.10	.07	1.18	2.02
50-100	1938	.21	1.05	2.16	.43	1.16	2.18	.15	1.43	2.07
100-150	40	.50	.83	2.24	.32	.80	2.02	.06	.74	1.88
150-200	13	.50	.92	2.87	-.07	.83	2.35	-.42	.96	2.54
overall		.08			.37			.10		

Table 1c

Comparison between radar 5 (Chenies) and Met. Office gauges - July 1995

		Uncorrected			Corrrected			Adjusted			
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	RMSf*
0- 50	46	.45	1.03	2.32	.45	1.03	2.32	.13	1.07	2.38	1.8
50-100	57	.20	1.08	2.26	.29	1.02	2.28	-.07	1.17	2.39	1.8
100-150	91	-0.84	2.44	2.88	.39	1.50	2.52	-.07	1.83	2.57	2.0
150-200	34	-7.51	18.18	4.01	-.78	4.35	2.73	-2.57	7.79	3.04	2.5
overall		-1.31			-.21			-.40			

* best estimate of the fractional error in hourly surface precipitation taking representative errors into account.

Table 2

a) Comparison between radar 5 (Chenies) and Met. Office gauges within 100km
The comparison is between average rates at each gauge site during Jan 1995

Uncorrected		Corrected		Adjusted	
Mean	RMS	Mean	RMS	Mean	RMS
mm/h	mm/h	mm/h	mm/h	mm/h	mm/h
0.32	0.52	0.50	0.54	0.06	0.32

b) Similar to a) but for NRA Thames gauges within 100km of Chenies radar

0.14	0.33	0.46	0.50	-0.00	0.23

Note: Gauge adjustment was applied manually and retrospectively to these data. The adjusted mean differences are therefore subject to some uncertainty but this should be small compared to the differences in the Table.

Table 3a

Comparison between radar 17 (Dublin) and hourly gauge data (UK and Irish Met. Office) for the period 17th Mar to 1st Aug 1995

		Uncorrected			Corrected			Adjusted		
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf
0- 50	108	-.44	1.39	2.94	-.21	.94	2.80	.11	.79	2.69
50-100	115	-.64	1.55	3.21	-.47	1.15	3.09	-.04	.97	2.61
100-150	666	-.79	2.11	3.15	-.22	1.13	2.64	.16	1.07	2.47
150-200	875	-.14	1.64	2.63	-.34	1.48	2.73	.17	1.33	2.61
Overall		-.44			-.29			.15		

Table 3b

Comparison between radar 8 (Predannack) and Met. Office hourly gauge data for the period 17th Mar to 1st Aug 1995

		Uncorrected			Corrected			Adjusted		
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf
0- 50	75	.74	1.05	2.79	.77	1.07	2.82	-.03	1.14	2.00
50-100	88	.66	1.16	2.24	.64	1.06	2.33	-.34	1.08	2.07
100-150	13	-.55	3.73	3.61	1.27	2.63	3.32	-.27	2.91	2.77
150-200	38	.34	3.47	5.27	.84	2.14	3.75	-.42	2.52	4.06
Overall		.56			.76			-.24		

Table 3c

Comparison between radar 5 (Chenies) and Met. Office hourly gauge data for the period 17th Mar to 1st Aug 1995

		Uncorrected			Corrected			Adjusted		
Range km	Number	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf	Mean mm/h	RMS mm/h	RMSf
0- 50	258	.07	.95	2.22	.20	.91	2.18	-.01	.93	2.26
50-100	346	.11	.83	2.11	.31	.84	2.13	.02	.89	2.23
100-150	511	-.11	1.43	2.34	.48	1.19	2.26	.03	1.31	2.40
150-200	135	-1.56	9.17	3.05	.27	2.36	2.79	-.71	4.16	3.03
Overall		.17			.23			-.06		